The Space Infrared Telescope Facility (SIRTF)

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ABSTRACT

This paper describes the design of the Space Infrared Telescope Facility (SIRTF) as the project enters the detailed design phase. SIRTF is the fourth of NASA's Great Observatories, and is scheduled for launch in December 2001. SIRTF provides background limited imaging and spectroscopy covering the spectral range from 3 to 180 μm, complementing the capabilities of the other Great Observatories – the Hubble Space Telescope (HST), the Advanced X-ray Astrophysics Facility (AXAF), and the Compton Gamma Ray Observatory (CGRO). SIRTF will be the first mission to combine the high sensitivity achievable from a cryogenic space telescope with the imaging and spectroscopic power of the new generation of infrared detector arrays. The scientific capabilities of this combination are so great that SIRTF was designated the highest priority major mission for all of US astronomy in the 1990s.

Keywords: telescope, cryogenic, infrared, astronomy, astrophysics, Great Observatory

1. INTRODUCTION

The SIRTF mission has experienced dramatic evolution in both architecture and mission design. Originally conceived as a low Earth orbiting observatory serviced by astronauts from the Space Shuttle, SIRTF passed through a phase in high Earth orbit using first the Titan and later the smaller Atlas launch vehicle, to the current concept of a deep-space mission orbiting the sun, and using the still smaller Delta launch vehicle. SIRTF features an 85 cm aperture telescope at 5.5 K, and three science instruments with focal plane detectors cooled as low as 1.5 K. SIRTF carries 360 liters of superfluid helium cryogen, which is expected to last in excess of 2.5 years. Several innovative design features have enabled the mission to retain the majority of the originally envisioned science capability at a fraction of the original cost and mass. The Observatory is shown in Figure 1.

1.1 Solar orbit

The foremost breakthrough enabling a low cost SIRTF is the solar orbit. A fundamental challenge in designing a cryogenic system is the need to minimize the heat load (especially the parasitic heat load) to the cryogen, which determines the quantity of cryogen required to achieve a given lifetime. Three sources of parasitic heat must be successfully managed: heat from the sun, heat from the Earth, and heat from warm portions of the vehicle. The solar orbit conveniently eliminates the Earth as a heat source by having the Observatory trail behind the Earth in a 1 AU orbit, drifting away at a rate of approximately 0.1 AU per year. Once the Earth is removed from the picture, a number of simplifications occur. By shading the Observatory with a solar panel facing the sun, the remaining outer surfaces of the vehicle view cold space. Instead of covering those outer surfaces with insulating MLI they can be designed instead to radiate to space, providing a powerful cooling capacity for lowering the temperature of those portions of the vehicle surrounding the cryostat. The passive cooling design of SIRTF is expected to lower the temperature of the outer shell to an unprecedented 40 K. The parasitic heat load is thus radically reduced (< 1 mW for SIRTF), enabling a design where cryogen is used in the most efficient way possible – only to absorb the heat dissipated by the science detectors (< 8 mW for SIRTF).

Further information on the SIRTF mission can be found on the Home Page: http://sirtf.jpl.nasa.gov/sirtf

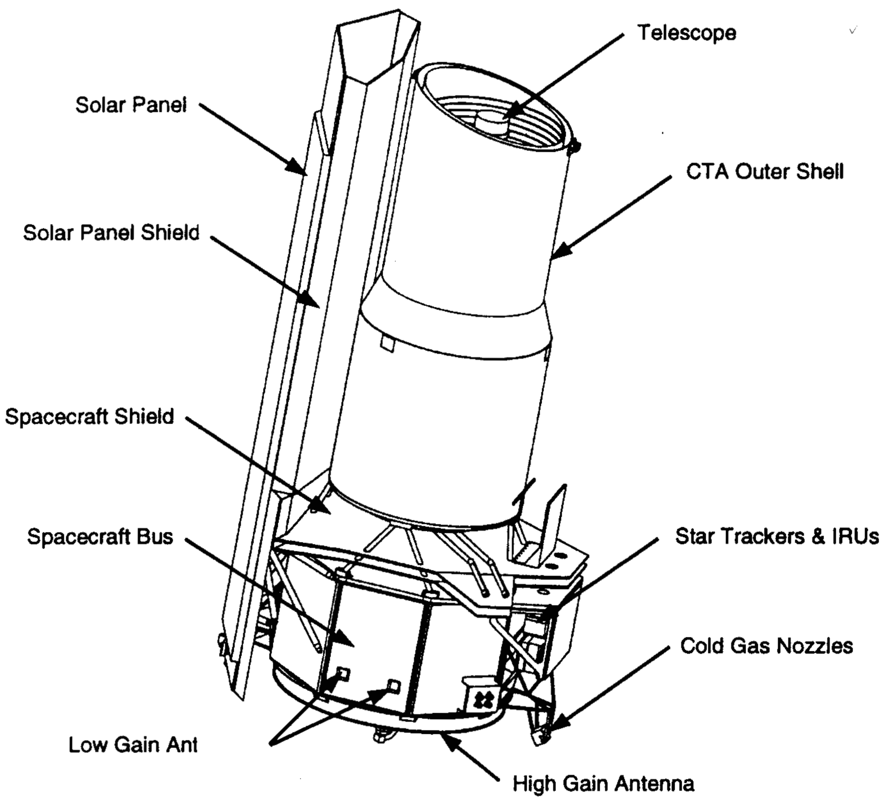

Figure 1. The Space Infrared Telescope Facility (SIRTF).

1.2 Warm launch architecture

The reduced requirement for cryogen makes possible another innovation that we call the *warm launch* architecture, which further reduces the mass of the Observatory. Past cryogenic space telescope designs, such as the Infrared Astronomy Satellite (IRAS) launched in 1981, and the European Infrared Space Observatory (ISO) launched in 1995, enclose both the telescope and the science instruments in a cryostat, maintaining the entire optical train at or near the temperature of the cryogen. The vacuum shell resulting from such an arrangement is relatively large and massive. The warm launch architecture encloses only the science instruments in a cryostat; the telescope is mounted externally to the vacuum shell, as shown in Figure 2. The size and mass of the cryostat is thus significantly reduced.

New features of this approach include the telescope being warm at launch (hence the name), the need for a vacuum door between the telescope and the science instruments which must be opened after launch, and a situation where the telescope temperature depends on the amount of heat dissipated to the cryogen. Passive cooling alone lowers the telescope temperature to approximately that of the outer shell (40 K). Further cooling is achieved by heat sinking the telescope to the helium vent line, utilizing the cooling power of the vapor that is boiled off by the focal plane heat absorbed. Careful design succeeds in cooling the telescope to 5.5 K with only 6mW of focal plane heat absorbed by the cryogen. Should the focal plane heat dissipation be reduced, the temperature of the telescope would rise. It is a happy coincidence that the instrument requiring the coldest telescope temperature happens to dissipate the greatest amount of focal plane heat.

1.3 Observatory configuration

The Observatory comprises five major systems: three science instruments, including the Infrared Array Camera (IRAC), the Infrared Spectrograph (IRS), and the Multiband Imaging Photometer for SIRTF (MIPS); the Cryo-Telescope Assembly (CTA), which includes the telescope, cryostat, passive cooling shields and radiators, and which houses the cold portions of the science instruments; and the Spacecraft, which includes the power, telecommunications, pointing control, command and data handling, and reaction control subsystems, and which houses the warm portions of the science instruments. The Observatory control mass is 905 kg, and it will be launched on the Delta 7920H rocket. The following sections describe the SIRTF systems in greater detail.

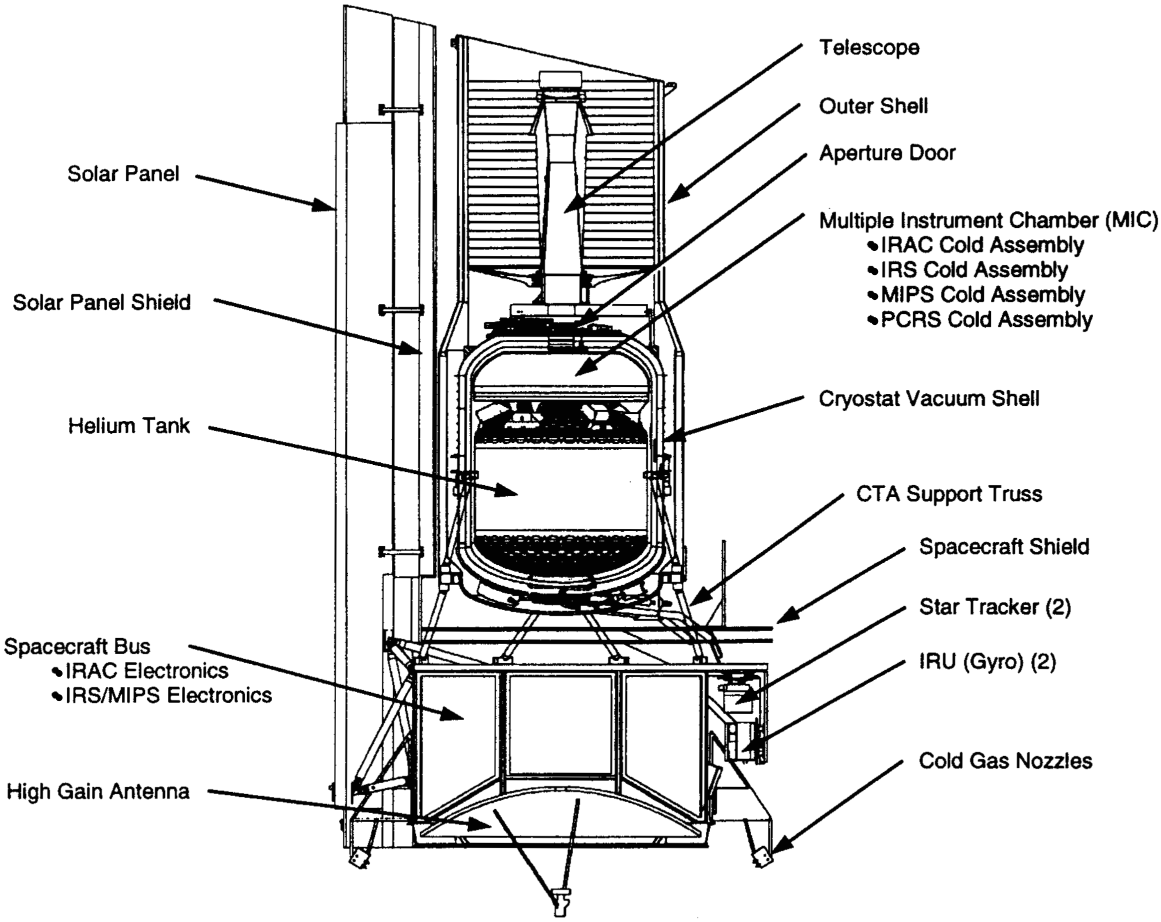

Figure 2. Cutaway view of SIRTF Observatory.

2. CRYO-TELESCOPE ASSEMBLY

The Cryo-Telescope Assembly (CTA) provides a 5.5 K telescope delivering 6.5 μm diffraction-limited imaging to three science instruments maintained at or near 1.4 K. The cryogenic design lifetime requirement for the CTA is 2.5 years, with a 5 year goal. The CTA comprises four main parts: the superfluid helium cryostat; the multiple instrument chamber (MIC) which houses the cold portions of the science instruments; the lightweight 85 cm aperture Ritchey-Chrétien telescope; and the outer-shell group, including the outer shell, solar panel shield and Spacecraft shield.

The CTA is mechanically mounted to, but thermally isolated from, the Spacecraft bus by means of low conductivity gamma-alumina struts. The solar panel, which is structurally cantilevered from the Spacecraft bus, shades the CTA from the sun at all times. The CTA is also thermally isolated from the solar panel and Spacecraft bus by means of low emissivity radiation shields.

2.1 Cryostat

The cryostat comprises the vacuum shell, superfluid helium tank, multiple instrument chamber (MIC), two inner vapor-cooled shields, aperture door, photon shutters, and plumbing associated with cryogen management. The cryogenic lifetime requirement is met with 360 liters of superfluid helium. The telescope is mounted to the outside of the vacuum shell on kinematic supports; the telescope barrel baffle is also mounted to the outside of the vacuum shell and incorporates a light-tight indium seal. The aperture door, which provides a vacuum seal, features a gold-coated window to enable short wavelength end-to-end optical testing prior to launch. A light-tight photon shutter is located between the aperture door and the science instruments in order to minimize the parasitic heat load through the aperture door during ground operations, and to provide a sufficiently low background for meaningful testing of science instruments. The shutters are opened prior to launch. The location of these components is detailed in Figure 3.

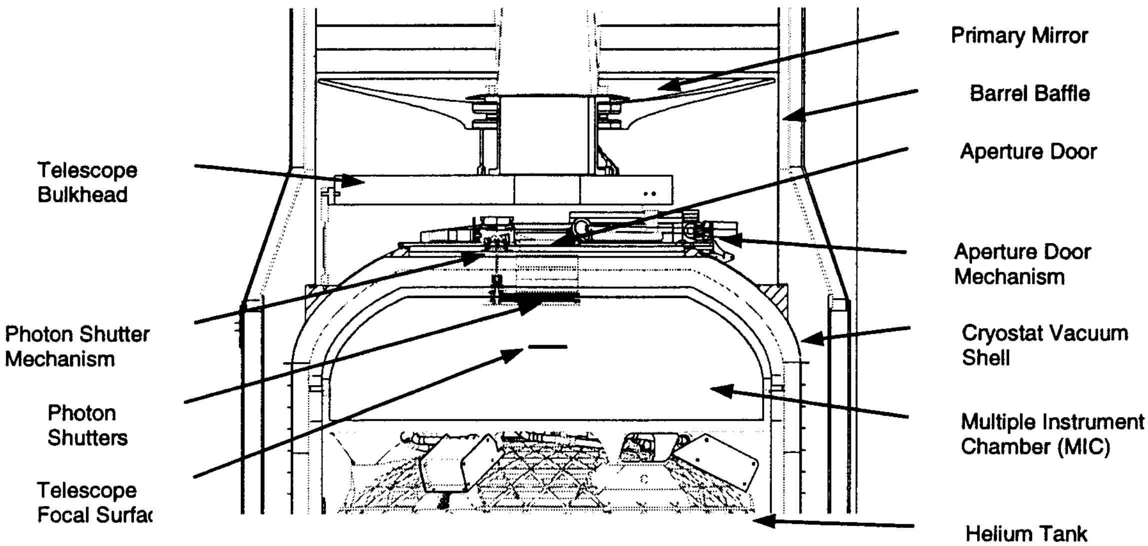

Figure 3. CTA detail showing cryostat, MIC, aperture door and photon shutters.

The cryostat vacuum shell is of lightweight 6061 aluminum construction, with cylindrical sections, a girth ring, and elliptical heads. A bolted flange at the girth ring near the middle of the cryostat permits disassembly for installation of the helium tank and MIC. The cryostat vacuum shell is supported from the base ring of the CTA via four strut bipods made of gamma-alumina material. Three bipods support the top of the helium tank from the vacuum shell girth ring. These bipods have titanium end fittings with integral flexures to accommodate the ground-to-orbit change in temperature gradient between the vacuum shell and helium tank. All of the struts have internal radiation baffling.

The helium tank is similar in construction to the vacuum shell with a cylindrical section and elliptical heads. It has a warm volume of 378 liters and a cold volume of 363 liters (due to aluminum shrinkage), and contains internal fluid level sensors, fill and vent lines, and slosh baffles. Structural mounting points for the MIC and the gamma-alumina support struts are located on the shoulder-portion of the helium tank head. The MIC is hard-mounted to the top of the helium tank, and the cold manifold is located beneath the MIC, just outside the helium tank.

The cryostat contains two vapor-cooled shields placed between the helium tank and the vacuum shell which are supported by the helium tank support struts through flexures. Standard multilayer insulation constructed of doubly aluminize mylar with a net separator is placed on both sides of the vapor cooled shields. Plumbing includes the porous-plug (phase separator) interface to the helium tank, fill, vent, and crossover valves. In addition, approximately 1,300 conductors, forming the cryogenic cable harness, are routed between the MIC and the Spacecraft bus.

2.2 Multiple instrument chamber

The MIC is a photon-tight chamber 84 cm in diameter by 20 cm high, which contains the cold portions of the science instruments and the pointing calibration reference sensor (PCRS, a component of the pointing control system). Its design features a 6061 aluminum ribbed baseplate and cover, with an indium gasket photon seal, and photon tight electrical and thermal feedthroughs. The science instruments mount directly to coplanar mounting pads on the baseplate. Each instrument is thermally heat-sunk to the cryostat through high purity copper straps, with indium joints at each end. The arrangement of science instruments in the MIC is shown in Figure 4.

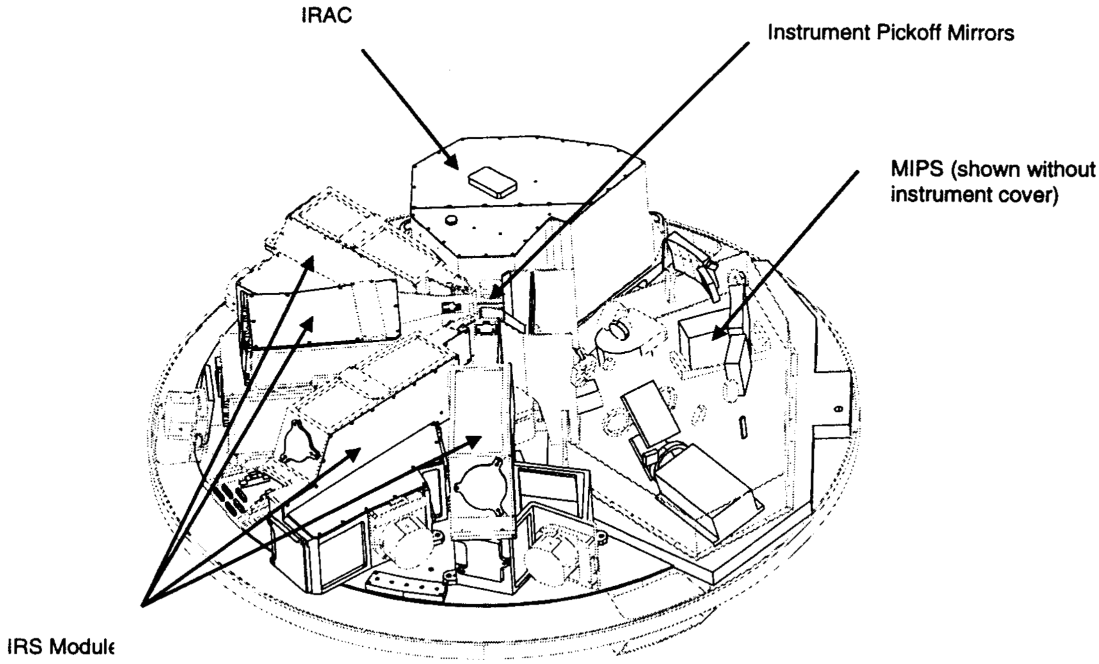

Figure 4. Science instrument arrangement on MIC baseplate.

2.3 Telescope

The SIRTF telescope is an 85 cm aperture Ritchey-Chrétien design with the characteristics listed in Table 1. The telescope is required to deliver diffraction limited performance (0.07 waves rms) at 6.5 μm across the entire 32 arcmin field of view, while operating at 5.5 K. The lightweight design comprises a single arch primary mirror, secondary mirror, central metering tower, support bulkhead and focus mechanism, with a total mass of less than 50 kg. All components of the telescope, apart from titanium flexures that support the primary and secondary mirrors, are made of HIP beryllium. A single-axis focus mechanism will be used in orbit to optimize focus for the short wavelength camera (IRAC).

The SIRTF telescope builds upon the successful IRAS beryllium telescope experience, and utilizes residual hardware from the Infrared Telescope Technology Testbed (ITTT) development program, which was directed at demonstrating key technologies for SIRTF. Guiding principles behind the SIRTF telescope design include:

- Maximize the use of materials with a very high stiffness/density ratio, high thermal conductivity, and low cryogenic specific heat,
- Build the entire telescope of the same material, not only to minimize mass, but to preclude coefficient of thermal expansion (CTE) mismatch complications, and to make the telescope assembly as dimensionally stable as possible,
- Select a configuration that minimizes the size of the major elements of the telescope assembly, and,
- Strive for the simplest possible design to drive down the part-count, thereby minimizing the time and cost for design, fabrication, and integration.

Figure 5. Prototype SIRTF telescope undergoing random vibration testing.

SIRTF benefits from significant advances in beryllium powder metallurgy. The ITTT primary mirror has been demonstrated to have no measureable hysteresis upon temperature cycling between 5 K and 300 K, and has been successfully null-figured based on a hit map developed from cryogenic optical wavefront measurements. The prototype SIRTF telescope has been aligned and optically tested at cryogenic temperature. A development random vibration test has also been successfully performed to validate the telescope structural model, and to verify the alignment stability. The prototype telescope was subsequently disassembled, and the primary mirror is currently being polished to flight specifications for use as the SIRTF flight article. A second primary mirror is also being fabricated as a flight spare. The back focal distance of the flight telescope is slightly shorter than that of the prototype telescope, requiring rework of the secondary mirror and slight alteration of the primary-to-secondary mirror despace. Figure 5 shows the prototype telescope on the vibration test table.

Table 1. Telescope characteristics.

Characteristic	Cold Value
Entrance pupil diameter	85 cm
Entrance pupil location	primary mirror
Primary mirror focal ratio	1.2
Back focal distance	43.7 cm
Entrance pupil central obscuration	outside diameter < 32 cm
Exit pupil diameter	12.1 cm
Exit pupil location	145.2 cm in the $+X$ direction from the vertex of the telescope focal surface
f-number	$f/12$ unvignetted beam to telescope focal surface
Field of view	32 arcmin diameter unvignetted
Spider obscuration (areal)	10%

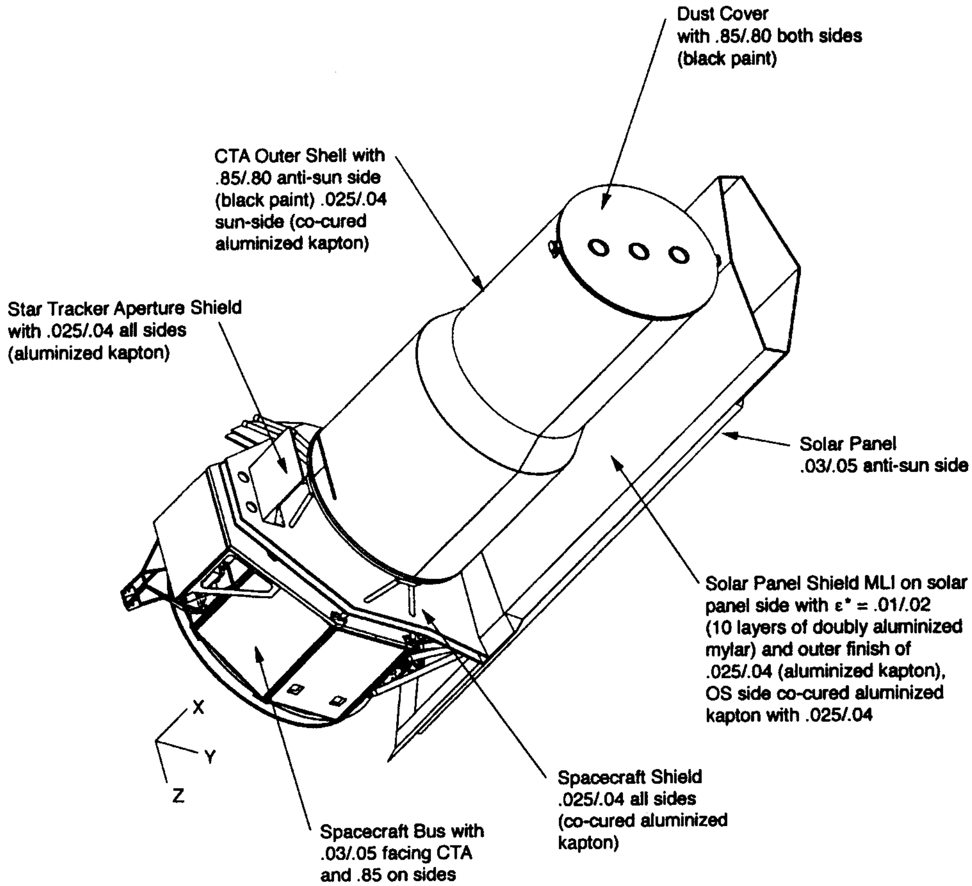

Figure 6. Nominal and worst case emissivity values for key Observatory surfaces.

2.4 Outer shell group

The CTA outer shell group (OSG) performs the passive cooling of the CTA. It includes the outer shell (with dust cover), outer vapor-cooled shield, thermal shields to block radiation from the Spacecraft and solar panel, and the CTA-to-Spacecraft interface structure.

The telescope assembly and cryostat are surrounded by the OSG, whose function is to intercept heat from the warm Spacecraft and solar panel, and reject it to space by radiation. The OSG accomplishes this through a combination of clever shield geometry and low emissivity surfaces. Figure 6 shows the nominal and worst case allowable emissivities for key Observatory surfaces.

The outer shell is closed at the top by an ejectable cover such that a dry nitrogen purge can be provided to prevent contamination of the mirrors and low emissivity surfaces before cooldown in orbit. The outer shell, dust cover, and outer vapor-cooled shield are constructed of lightweight all-aluminum honeycomb. The radiation shields are constructed of even lighter honeycomb built from high modulus/high thermal conductivity graphite/cyanate facesheets and aluminum core. The outer vapor-cooled shield is placed between the telescope assembly/dewar and the outer shell, and is supported from the cryostat support struts.

The thermal shields are sized and shaped such that the Observatory is shaded at all times while within the safe pointing zone, defined as a boresight orientation between 85-120 deg from the Observatory-sun line, and a roll angle orientation within ±2.5 deg from the solar panel facing the sun. A ±2 deg pointing recovery zone is added to this range to permit recovery from pointing system faults without solar illumination of OSG surfaces. The nominal heat flow map and predicted steady state temperatures are shown in Figure 7.

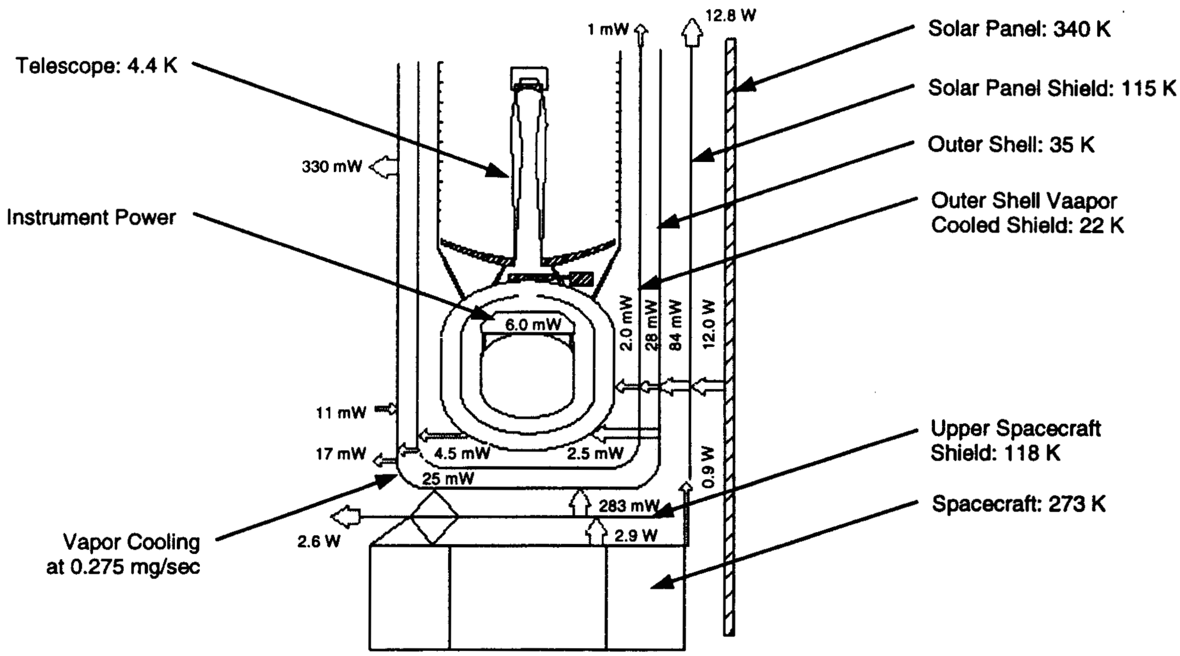

Figure 7. Heat flow map and steady state temperatures for nominal thermal parameters.

3. SPACECRAFT

The SIRTF Spacecraft provides the support functions necessary to operate the Observatory. It provides a dimensionally stable structure to which the CTA is mounted, and it provides electrical power, pointing control functions, telecommunications with the NASA Deep Space Network, and thermal control for the hardware mounted within. The Spacecraft comprises an equipment bus that houses the subsystem components as well as the warm portions of the science instruments, and a solar panel that shades the CTA and provides electrical power. The solar panel is cantilevered from the equipment bus, and supports the solar panel shield.

The Spacecraft bus structure is a modular design with nine bays arranged in an octagon. The CTA mounts to the upper deck of the bus at eight locations. All eight attach points are maintained at the same temperature by means of a heat pipe embedded in the deck, and are thermally isolated from the remainder of the bus. Isothermalizing the attach points helps maintain stable alignment between the CTA optical boresight and the pointing control system reference frame in the bus. The deck itself is constructed of aluminum honeycomb sandwiched between graphite/cyanate-ester composite facesheets. The composite bus materials were chosen for high stiffness, low CTE, and low water absorbptivity. Spacecraft equipment is structurally and thermally mounted to internal composite panels. Heat pipes embedded in these panels transport heat from the equipment to radiators on portions of the bus that view cold space. The Spacecraft is a dual-string architecture, with major components cross strapped at the interfaces. Figure 8 shows the layout of equipment in the bus.

3.1 Command and data handling

The Command and Data Handling (C&DH) subsystem receives, interprets, validates, and executes stored sequence commands. The C&DH coordinates and controls the activities and operations of other Spacecraft subsystems and the science instruments. The C&DH design is based on inheritance from the Mars Surveyor and Stardust programs, and utilizes the RAD-6000 processor, which can operate at a clock speed of up to 20 MHz. Data packetization, compression, and Reed-Solomon encoding are performed by the C&DH. High speed (1 Mbps) and low speed (19.2 kbps) RS422 interfaces are used for serial communications with the pointing control system components and the science instruments. Science data is stored in a solid state data recorder sized at 8 Gbit per string, both strings being accessible for downlink. The nominal mission design calls for a downlink pass every 12 hours where up to 8 Gbits of data is transmitted to the ground. Transmitted data is maintained in mass memory until the next downlink pass in order that any missed packets may be retransmitted.

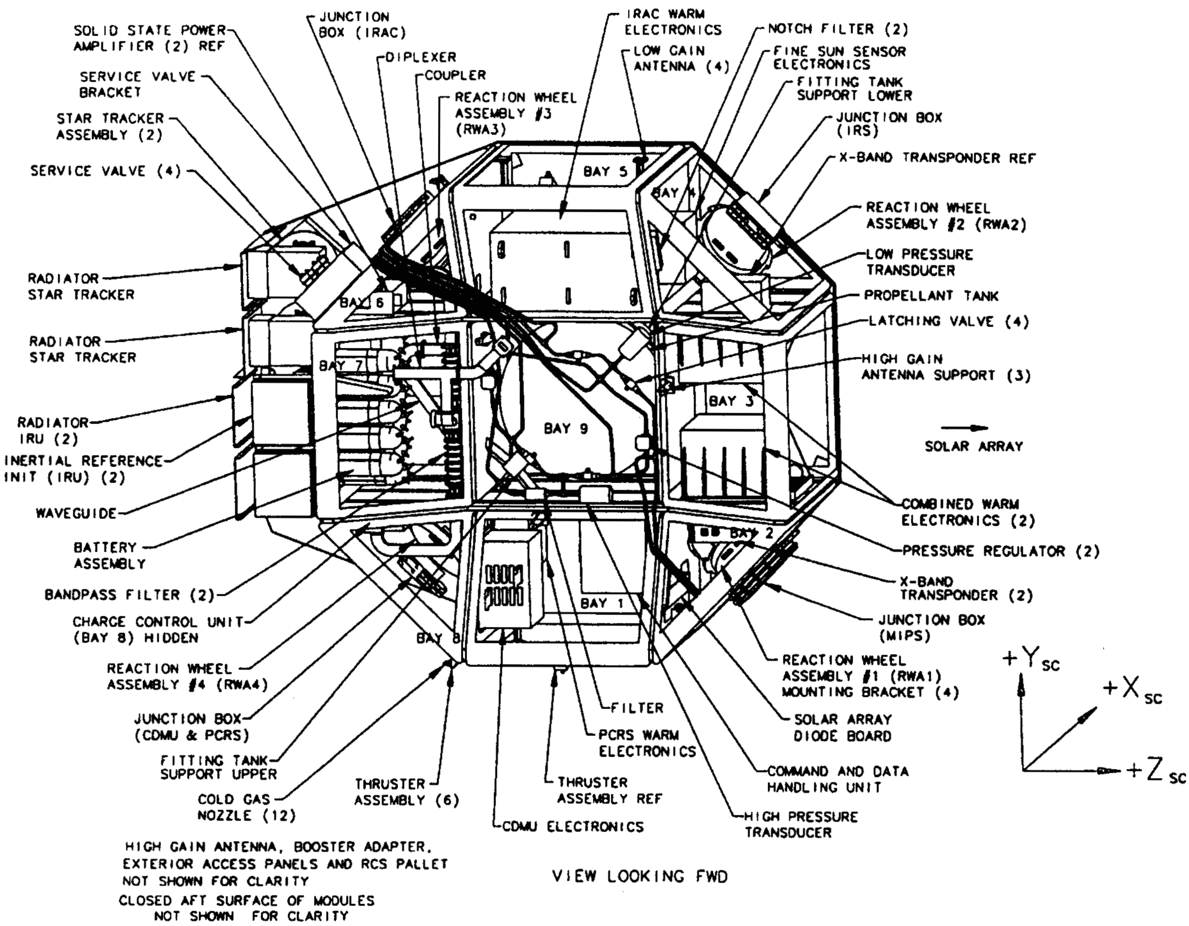

Figure 8. Layout of equipment in the Spacecraft bus.

3.2 Telecommunications

The all X-band telecom subsystem receives uplink commands and transmits science and engineering data to the ground. It utilizes a new generation Small Deep Space Transponder coupled to a 20-watt solid state power amplifier and various microwave components. The single high gain antenna (HGA) is a 1.35 m parabolic dish with approximately 39 dB gain; the four low gain patch antennas (LGAs) provide approximately 7.5 dB and 6 dB gain for downlink and uplink, respectively. The LGAs are arranged with one transmit/receive pair pointing in the *+Y* direction, and one transmit/receive pair pointing in the *-Y* direction, thus providing nearly complete spherical coverage. The primary uplink is 2 Kbps via the HGA with emergency commanding at 7.8 bps via the LGA. Nominal downlink via the HGA is 2.2 Mbps during the first 2.5 years (out to a distance of 0.32 AU), dropping to 1.1 Mbps for the next 2.5 years using the 34 m HEF ground stations, or continuing at 2.2 Mbps using the 70 m stations.

3.3 Pointing control

The pointing control subsystem (PCS) provides the hardware and flight software necessary to control, stabilize, and determine Observatory pointing orientation. The PCS provides the capability to place and stabilize (or scan) science targets within the science instrument fields of view, maintains the solar array pointed toward the sun, and points the HGA toward Earth for downlink. The PCS ensures that pointing constraints are not violated, and safes the Observatory in the event of a fault.

The PCS employs a celestial-inertial, three-axis stabilized control system. Attitude determination and reconstruction is provided by a star tracker/inertial reference unit (ST/IRU) package that is mounted externally to the Spacecraft bus. Since there is no realtime pointing error sensor in the CTA focal plane, stable coalignment of the telescope boresight and the PCS reference frame is crucial to SIRTF operation. This is enabled by the very stable thermal environment inherent in the solar orbit, and by careful design of the metering path between the CTA and the ST/IRU. Periodic calibration of the CTA boresight is possible by means of the pointing calibration reference sensor (PCRS) located in the CTA focal plane. Calibration of the boresight in J2000 coordinates is achieved by placing a Tycho catalog reference star on the PCRS, which measures the visible wavelength centroid of the star. Infrared targets for which accurate coordinates are not known can be located by means of an infrared peak-up camera in the IRS instrument, which performs autonomous centroiding of features in the scene. Knowledge of the boresight orientation degrades to about 5 arcsec rms during slew maneuvers because of residual bias error terms in the ST, but precision maneuvers that transfer targets from the peak-up array (or PCRS) to spectrograph slit locations can be effected to an accuracy of 0.4 arcsec rms. Once on target, the PCS can stabilize the line of sight to 0.3 arcsec rms over a 200 sec correlation time. The boresight can also be scanned across the sky at rates of up to 20 arcsec/sec for large area scan mapping. Because SIRTF is outside of the Earth's magnetic field, momentum management is accomplished by means of a cold gas (N_2) reaction control system which desaturates the four reaction wheels used to control Observatory attitude. The volume of propellant has been sized to provide a five year lifetime.

4. SCIENCE INSTRUMENTS

SIRTF has three focal plane instruments, the Infrared Array Camera (IRAC), the Infrared Spectrograph (IRS) and the Multiband Imaging Photometer for SIRTF (MIPS). All three utilize large format infrared detector arrays that can operate at the natural background limit of sensitivity, which is determined by the thermal emission of the zodiacal dust for the spectral range over which SIRTF operates. The unique scientific power of SIRTF derives from the combination of a telescope cold enough to eliminate all sources of infrared emission except cosmic backgrounds and the use of large format arrays that can provide the full measure of performance thus made possible.

The design of all three instruments has been focused by the four defining science programs for SIRTF. This approach guided selection of a set of complementary capabilities that together support a coherent body of observations. The IRAC provides large-field imaging in four bands between 3 and 9 μm. The IRAC bands were selected to characterize the starlight from distant galaxies, allowing estimation of their redshifts, and to identify nearby substellar objects (brown dwarfs) by measuring their cool spectral energy distributions. The MIPS supports large field mapping and high resolution imaging bridging from the mid infrared to the submillimeter. Its concept is centered around the study of the far infrared emission of distant galaxies due to ultraviolet and visible energy absorbed and reradiated at longer wavelengths by their interstellar dust, and the analysis of the systems of debris around nearby stars associated with possible planetary systems. The IRS provides low resolution spectroscopy from 4 to 40 μm to probe the composition of these debris systems and the nature of interstellar dust in highly redshifted galaxies. It also provides moderate resolution spectra to study the emission lines from infrared-bright galaxies to determine their sources of energy.

At the same time, previous missions and current high priority science investigations demonstrate that the capabilities of the SIRTF instruments are very general in their potential application. The European Space Agency Infrared Space Obervatory (ISO) has shown that the 4 to 40 μm spectral region is rich in both emission lines and broad molecular features. The increased sensitivity of IRS resulting from its high performance arrays allows these features to be probed to far fainter levels than with ISO. The MIPS will give a much deeper look at the far infrared sky than was provided by either ISO or the predecessor Infrared Astronomy Satellite (IRAS) which surveyed the entire sky 15 years ago. Since there are currently no plans for a future far infrared space mission, the archive of MIPS data will be a fundamental scientific resource for many years. The near to mid infrared imaging by IRAC provides a reconnaisance of many of the science themes that have created interest in the Next Generation Space Telescope (NGST), for which IRAC and SIRTF provide an important scientific and technical precursor. These general capabilities will be applied by the international astronomical community to the broad range of problems that will be at the astronomical forefront at the time of the SIRTF mission.

At the same time, the SIRTF instrument designs have been subject to strict cost constraints. For example, cryogenic mechanisms have been kept to a minimum of two, a shutter in IRAC and a scan mirror in MIPS. Rather than providing flexibility and multiple operating modes with filter wheels, moving spectrograph gratings, and beam directing mirrors, the instruments have multiple optical paths that feed separate detector arrays, with each path dedicated to a specific capability. The resulting drastic reduction in the number of operating modes for the instruments will substantially simplify both ground test and space operations, creating savings in both cases. Further savings are achieved in many ways, for example through sharing of the instrument electronics by the IRS and MIPS, and by constructing arrays with different types of infrared sensor using identical readouts, a step taken by all three instruments to reduce development costs and to simplify the array control electronics and software. It is through the combination of highly cost-conscious design, the use of powerful new array technologies, the design of a complementary suite of instruments with a scientific focus, and the ability to take full advantage of a cold telescope, that SIRTF can achieve the power of a Great Observatory on what used to be an Explorer budget. Figure 9 shows the location of the various instrument fields of view in the shared SIRTF focal plane.

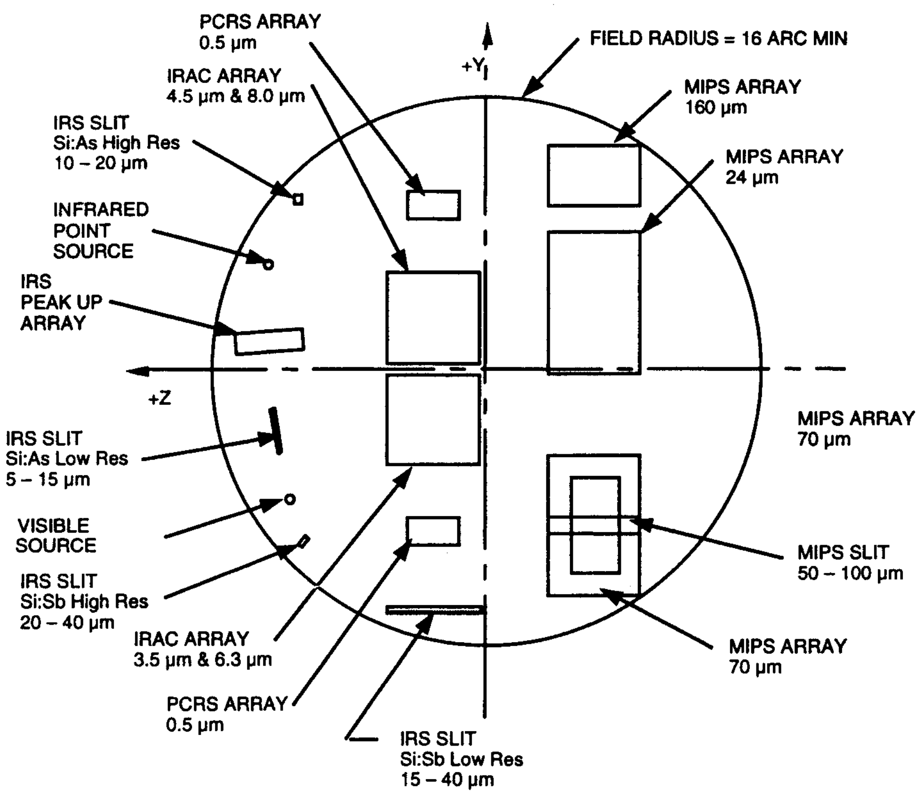

Figure 9. Science Instrument fields of view in SIRTF focal plane.

4.1 Infrared array camera

The Infrared Array Camera (IRAC) is a four-channel imager which is part of the SIRTF cyrogenic instrument volume. Simultaneous 5.12 x 5.12 arcmin images at 3.5, 4.5, 6.3 and 8.0 µm are provided with 25% bandwidth at each wavelength. The pixel size is 1.2 arcsec in all bands. Two adjacent fields of view in the SIRTF focal plane support the four channels in pairs (3.5 and 6.3 µm; 4.5 and 8.0 µm). All four detector arrays in the camera are 256 x 256 pixels in size, with the two short wavelength arrays using InSb and the two longer wavelength arrays Si:As as the detector material. The IRAC sensitivity (5 σ, 200 sec) at 3.5, 4.5, 6.3 and 8.0 µm is 4.1, 5.2, 29 and 49 µJy, respectively.

The only moving part in IRAC is a shutter located near the entrance aperture of the camera. The rear of the shutter blade contains a diffuse surface which, when the shutter is closed, allows light from a transmission calibration source in IRAC to enter the instrument optics. With the transmission calibrator off, the closed shutter also serves as a dark slide, blocking all radiation from entering the camera. Each array also has associated with it a flood calibrator which is used for testing.

The IRAC instrument addresses, in particular, two of the four major scientific objectives defining the SIRTF mission. These objectives are (1) the study of the formation and evolution of normal galaxies in the early Universe, and (2) the study of the low end of the stellar luminosity function and the detection of brown dwarfs and superplanets. To carry out studies of the early Universe, IRAC will perform deep near-infrared surveys to detect a sufficient number of normal galaxies to measure the luminosity function of these galaxies as a function of redshift (z) to $z \geq 3$. Galaxy redshifts will be determined by three-color photometry. For the brown dwarf survey, the IRAC instrument will survey several hundred square degrees to a shallower flux level to search for brown dwarfs and superplanets and explore the low mass end of the stellar mass function. These objects will be initially selected on the basis of photometric colors (3.5/4.5 μm), and their identification verified by the detection of proper motion in a subsequent observation approximately one year later.

As a byproduct of these observations the IRAC instrument will produce a data base which can be important for a wide variety of additional investigations. These very sensitive large area surveys will be a significant legacy of this program and an important astronomical resource far into the future.

Development, construction and flight of IRAC is a joint project of the Smithsonian Astrophysical Observatory, NASA/Goddard Space Flight Center, NASA/Ames Research Center, University of Rochester, and the University of Arizona. The infrared arrays will be constructed by the Raytheon/Santa Barbara Research Center and will be tested and evaluated by the University of Rochester, NASA/Ames Research Center and the NASA/Goddard Space Flight Center. Further information about IRAC can be obtained from the papers in SPIE Conference on Infrared Astronomical Instrumentation (SPIE Vol. 3354) Ref. 1 (instrument description, 114), Ref. 2 (InSb arrays, 02), and Ref. 3 (Si:As arrays, 10), and from Ref. 4 Si:As and Ref. 5 on InSb array detectors. The IRAC Home Page is located at http://cfa-www.harvard.edu/cfa/oir/Research/irac/firstpage.html.

4.2 Infrared spectrograph

The SIRTF Infrared Spectrograph (IRS) provides SIRTF with low and moderate-spectral resolution capabilities between 4 and 40 μm. In order to reduce the instrument development and testing costs, the IRS has no moving parts, employs simple flat gratings and surfaces of revolution in its optics, and has all-aluminum optics, mounts, and housings. The cryogenic portion of the instrument is divided into four separate enclosed modules, each with its own pick-off mirror in the SIRTF telescope focal surface and each with its own infrared detector array. The four modules will be built and tested separately and then joined to a common IRS baseplate, which in turn is attached to the floor of the SIRTF multiple instrument chamber. The primary thermal path is through dedicated thermal links between the IRS Focal Plane Mount Assemblies (FPMAs) and the SIRTF cryostat; there is no requirement for the IRS module enclosures to carry any heat. Ionizing radiation shielding is provided primarily by the IRS FPMAs, with extra wall thickness in some locations in the module enclosures as needed to provide at least 1.8 cm path length through aluminum along any direction to the IRS detectors. All of the IRS detector arrays are 128 x 128 pixels in size and use blocked impurity band (BIB) conduction technology. When powered up and taking data, each of the arrays dissipates less than 1 mW of power into the SIRTF cryogen. Further information about the IRS detector arrays can be found elsewhere[6]. The characteristics of the IRS modules are given in Table 2 and described below.

Table 2. IRS module characteristics.

Module Name	Wavelength coverage (μm)	Spectral Resolution ($\lambda/\Delta\lambda$)	Field-of-View on the Sky (arcsec)
Short-low			
Imaging-blue	13-17	N/A	82 x 60
Imaging-red	21-26	N/A	82 x 60
Spectroscopy	4-15	50-120	3.6 x 109.2 (3.6 x 54.6 in each order)
Long-low	15-40	50-120	9.7 x 291.0 (9.7 x 145.5 in each order)
Short-high	10-19	~600	4.8 x 12.1
Long-high	19-37	~600	9.7 x 24.2

The Short-Low Module provides both low-resolution spectroscopy between 4 and 15 μm and two imaging channels centered at 15 and 23.5 μm, respectively. Two separate pick-off mirrors in the SIRTF focal plane feed separate spectroscopy and imaging optical trains which are then combined onto different regions on one focal plane detector array. The spectroscopy train is a singly-dispersed long slit design, with a pair of linear variable filters in front of the detector array to provide order-sorting. Although the short-low module is capable of spectroscopic operations down to 4 μm, the only performance requirements are levied between 6 and 15 μm. The two imaging spectral bands are provided by additional band-pass filters, also mounted in front of the detector array. Although the imaging fields can be used as small-field infrared cameras, their primary purpose is to provide a way to accurately measure the position of infrared objects with poorly known locations in the sky so that they can be placed in the IRS spectrograph entrance slits. The short-low imaging train is the only part of the IRS instrument that employs a Lyot stop. The short-low module uses a Si:As detector array that is anti-reflection coated with ZnS.

The Long-Low module is also of a singly-dispersed long slit design. Again, linear variable filters mounted in front of the detector array provide the needed order-sorting. The detector array is Si:Sb and is anti-reflection coated with diamond. The Short-High module uses a cross-dispersed echelle design. The entrance slit is designed to be as long as possible without causing overlap of different orders on the detector array. The detector material is Si:As and is anti-reflection coated with ZnS. The Long-High module also uses a cross-dispersed echelle design. The detector material is Si:Sb and is anti-reflection coated with ZnSe.

In low-resolution, the IRS has continuum sensitivity requirements of 0.55 mJy (5-sigma in 500 seconds of integration time) between 6 and 15 μm and 1.5 mJy (5-sigma in 500 seconds) between 15 and 40 μm. In high-resolution the IRS has a line sensitivity requirement of 3×10^{-22} W-cm^{-2} (5-sigma in 500 seconds) over 10-37 μm.

The IRS warm drive electronics are shared with the MIPS instrument. The IRS functions are provided by a CPU board, an I/O board that provides communication between the IRS/MIPS CPU and the Spacecraft CPU, a silicon detector array controller board, a silicon detector array signal processing board, and a data acquisition board that is used for monitoring selected voltages and temperatures in the instrument. The IRS/MIPS combined electronics have identical redundant A and B sides for additional reliability. Although all four IRS detector focal planes can be powered up and clocked at the same time, data from only one of the arrays can be read and stored at a time.

The IRS instrument development is managed and directed from Cornell University. Ball Aerospace and Technologies Corp. will provide the flight hardware and associated ground support equipment under a sub-contract with Cornell. Boeing North American will provide the detector focal plane mount assemblies under a sub-contract with Cornell. Additional information about the IRS can be found in other references[7,8]. The IRS Home Page is at http://astrosun.tn.cornell.edu/SIRTF/irshome.htm.

4.3 Multiband imaging photometer for SIRTF

The MIPS is built around three infrared detector arrays. A 128x128 pixel Si:As BIB device provides a spectral band at nominally 24 μm (20.5 to 26.5μm). This array is manufactured by Boeing (Rockwell) and has been developed under the leadership of the IRS team. A 32x32 Ge:Ga photoconductor array provides a band at 70μm (60 to 80μm) and a low resolution spectrometer. Finally, there is a 2x20 array of Ge:Ga photoconductors stressed to extend their response to 200μm and providing a band at 160μm (140 to 180μm). Both Ge:Ga arrays have been developed internally by the MIPS team and will be built at the University of Arizona, using detector material supplied by Lawrence Berkeley National Laboratories and readouts designed and fabricated by Hughes (Raytheon) Aerospace.

All bulk photoconductors, such as the MIPS Ge:Ga devices, have complicated reponse with time, and this behavior becomes prominent at the very low background levels provided by SIRTF. In addition to a prompt signal, space charge effects within the detector ("dielectric relaxation") produce an additional, very slow signal – in SIRTF with a time constant of tens of minutes. Additional complications occur because of the large gradients in conductivity at the contacts. These effects can make calibration difficult. Consequently, MIPS includes a scan mirror to allow rapid modulation of signals on the germanium arrays, so that measurements can be derived from the fast response component. The scan mirror also is used to improve operational efficiency and to switch the light into different optical trains within the instrument. Its design is based on the device developed for the Short Wavelength Spectrometer (SWS) on ISO.

MIPS can take observations in a number of ways. For large scale mapping, the 24 and 70 μm bands are projected by the instrument optics to fields of 5.3x5.3 arcmin and the 160 μm band to 0.5 x 5.3 arcmin (acutally 0.8x5.3 with a center pixel column blank). All three bands observe the sky simultaneously. The telescope will be tracked at a constant rate and the scan mirror will be driven in a countervailing sawtooth that will freeze images on the arrays for an integration time, and then advance them to a new position on the array with the flyback of the sawtooth. This operation avoids the overhead in conventional mapping due to multiply repointing and stabilizing the telescope. For photometry of single sources, the object is placed by telescope motions on each array sequentially and at each position the scan mirror is used to modulate the signal by chopping the image between positions. To provide a heavily oversampled Airy disk, the scan mirror can divert the beam for the 70μm band into a high magnification optical train that reduces the field to 2.6x2.6 arcmin and projects the pixels to $\lambda/3.5D$. The other two arrays have projected pixel sizes that oversample their respective Airy disks without a scale change. Computer processing of these highly sampled images can probe structures at the Rayleigh limit, or beyond (superresolution). To provide additional information about source spectra, the scan mirror can also divert the light into an optical train that feeds the Ge:Ga array through a low resolution spectrometer, providing spectral resolution of $\lambda/\Delta\lambda \sim 10$ from 50 to 95μm. In addition, the scan mirror can be used to block the view of the sky for all three arrays, providing a total power measurement of very extended source components and of large scale backgrounds.

Further information about the MIPS can be obtained from the papers in this proceedings on overall instrument design[9], unstressed Ge:Ga array[10], and stressed Ge:Ga array[11]. In addition, the MIPS scan mirror[12] and the Si:As BIB array[6] are discussed elsewhere. The MIPS Home Page is located at http://mips.as.arizona.edu/.

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